Characterisation of GRAiNITA : Test beam results Journées DI2I 2024

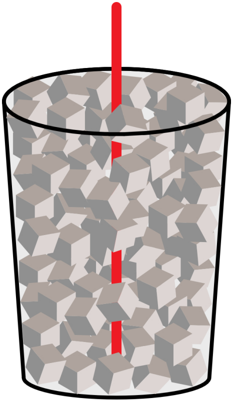
Hervé Chanal

on behalf of the GRAiNITA R&T members : S. Barsuk, D. Breton, I. Boyarintseva, A. Boyarintsev, A.M. Dubovik, B. Geoffroy, C.D. Goncalves, G. Hull, M. Imre, A. Kotenko, J. Lefrançois, M. Magne, B. Mathon, S. Monteil, S. Olmo, D. Picard, D. Reynet, M-H. Schune, N. Semkiv, I. Tupitsyna and M. Yeresko.

Introduction

GRAiNITA prototype

- Demonstrator for a new generation calorimeter
- Adapted to the constrains FCC-ee
- Allows a fine digitization of the electromagnetic cascade thanks to light confinement
- Reasonable cost



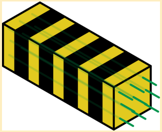
Collaboration

- ICJLab (Orsay-France)
- LPCA (Clermont-Ferrand-France)
- ISMA (Partner-Ukraine)

Concept of GRAiNITA

Shashlik calorimeter

Alternated layer of scintillator and absorber

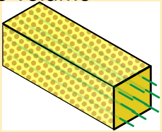


- High granularity
- Limited energy resolution :

$$\frac{\sigma_E}{E} \sim \frac{10\%}{\sqrt{E}}$$

GRAiNITA

Scintillator grain and absorber mixed in the same volume



- High granularity
- Expected energy resolution[1]:

$$\frac{\sigma_E}{E} \sim \frac{1\% \text{ to } 2\%}{\sqrt{E}}$$

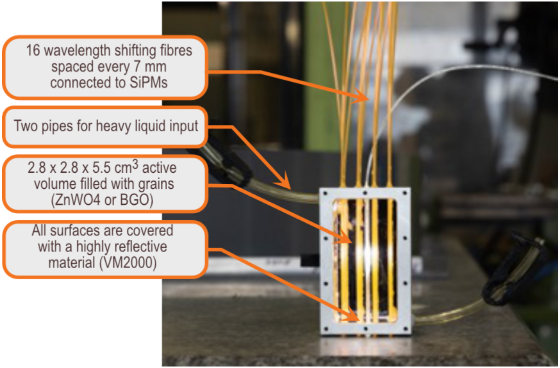
The energy resolution of a calorimeter can be written as :

$$\frac{\sigma_E}{E} \sim \frac{A}{\sqrt{E}} \oplus \frac{B}{E} \oplus C$$

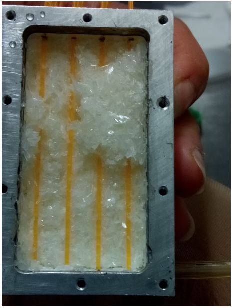
The determination of the C-term value is one of the challenges of the project.

[1] G4 simulation : Poster IEE/NSS 2024 : Energy resolution of the GRAiNITA protoype detector

GRAiNITA prototype



Empty prototype



Grain filling (ZnWO4)

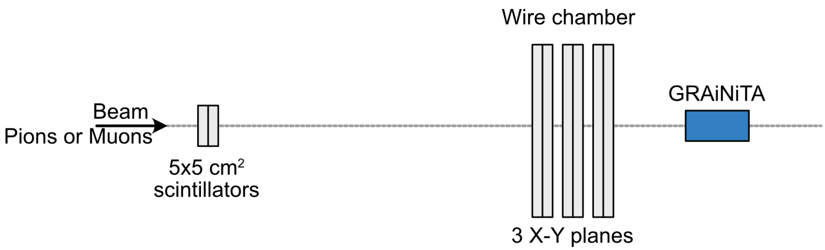
The GRAiNITA prototype is aimed at studying the performance of such a calorimeter :

- The number of photo-electrons per GeV
- The uniformity response (ex. close to a fiber or half-way)

Studies :

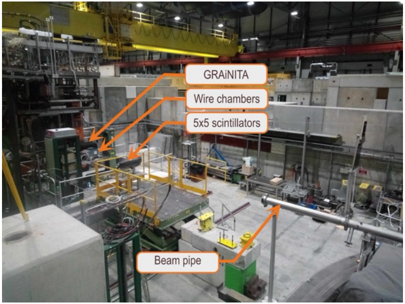
- Cosmics muons (2023-2024), Test beam (June 2024)

Test beam

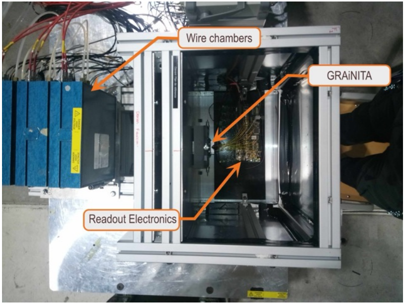


- Operated in June 2024 at CERN (North Area)
- Pions (a lot) and muons (fewer)
- GRAiNITA with water and heavy liquid
- Only water presented here because of a leak in the second case
- Scitillators located 2 m before GRAiNITA provide the trigger
- A wire chamber allows to perform track reconstruction

Some photographs



Installation in the North Area



Installation of the GRAiNITA prototype

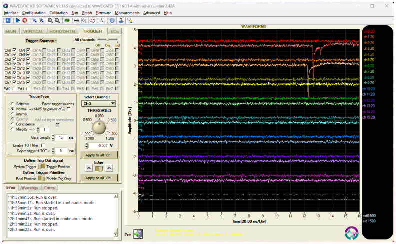
Fast acquisition system

Properties

- Digitiser : Wavecatcher
- Fast acquisition (> 1GHz) based on capacitor arrays
- 16 independent channels readout
- Allows single photon-electron (PE) counting during 25 μs
- Triggered by the 2 scintillators

Output

- Number of PE/channels for each event
- First μs acquired with the digitiser

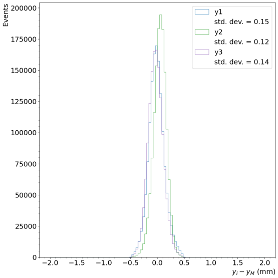


Acquisition software

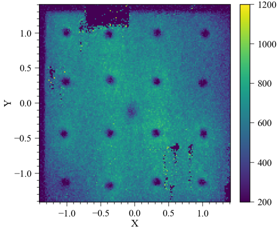
The wire chamber (DWC)

Properties

- Particles tracks reconstructed using the DWC
- DWC reconstructed track precision $< 250\ \mu m$
- First observable : projection of GRAiNITA mean number of PE/track on the DWC
- Fibres clearly seen
- Some dead zones (from the DWC)



Computed track resolution of the DWC

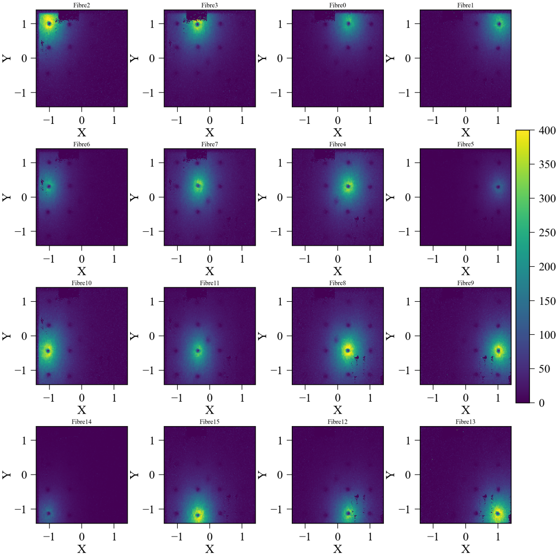


GRAiNITA projection on the DWC

Light confinement

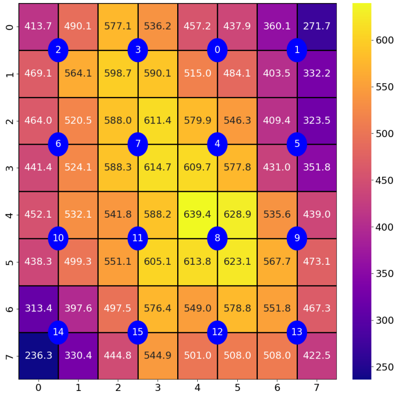
Properties

- The wavecatcher allows PE counting on 16 independent channels
- The contribution of each fibre to the total map can be observed
- Confirmation of the light is confined around its production

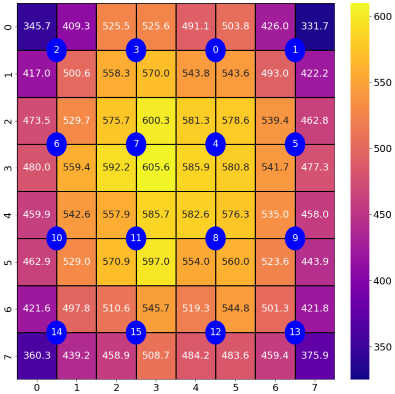


GRAiNITA projection on the DWC

Homogenisation procedure



Before the homogenisation



After the homogenisation

- Detector is splitted in 3.5 mm squares
- Mean number of PE is computed per square (fibre removed)
- Individual response of each of the 16 fibres is homogenised
- Special care will be made on the next iteration of the GRAiNITA detector to avoid this step

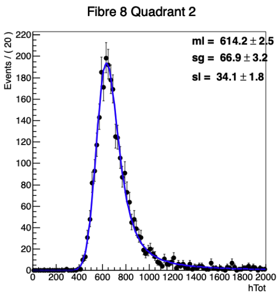
Deposited energy fits

Muons fit

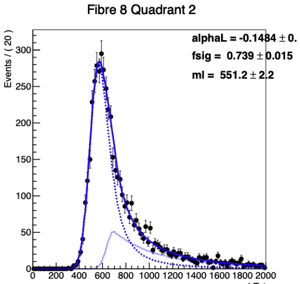
- Deposited energies follows a Landau convoluted by a Gaussian law (L-G)
- 3 parameters :
  - Landau position m_L and σ_L
  - Gaussian σ_G

Pions fits

- Pions can trigger a shower
- Modelled with a Chrystal-Ball with parameters derived from the L-G.
- σ_L and σ_G determined with the muons fits
- The signal fraction f_{sig} and α_L determined at this stage, only m_L will be free in the following steps



Muon (top) and pion (bottom)



Hit map definitions

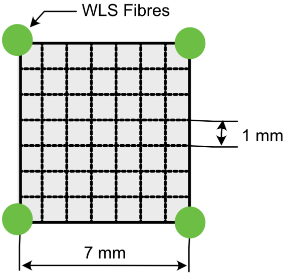
Virtual unit

Uniformity study :

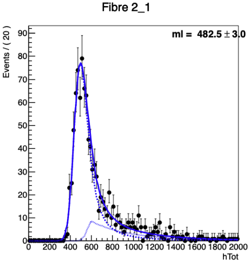
- Performance of a real size detector
- Need to define a base unit : square between 4 fibres, 1x1 mm^2 bins
- Use of pion data (statistics)
- Fits educated with the 3.5 cm squares studies

Virtual unit :

- Need to avoid border effect and the central clear fibre
- 2 virtual units build



Base unit (top), fit example (bottom)



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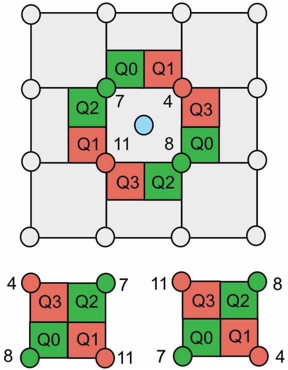

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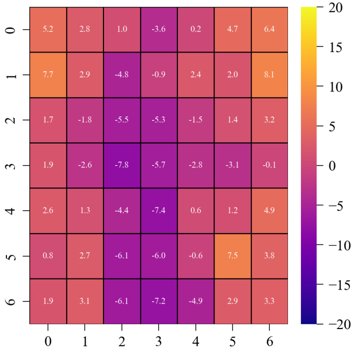
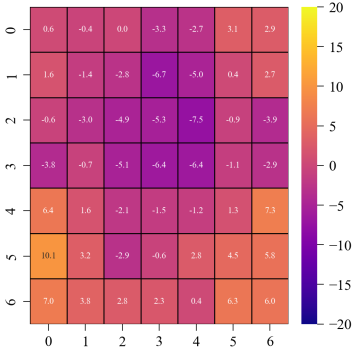
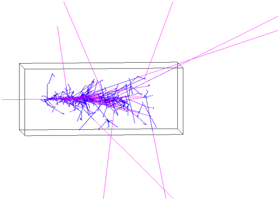




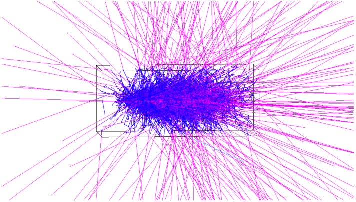
- Two maps
- Relative difference with the mean value (in %)

Geant4 simultion

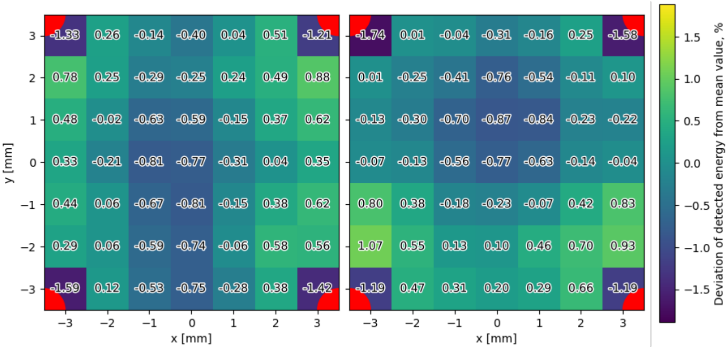
- Needed to determine the constant term
- Simulated a box of 168 by 168 by 400 mm, containing a grid of 28 by 28 WLS fibres evenly distributed
- Use a homogenous medium (80% $ZnWO_4$, 20 % water-based sodium polytungstate solution)
- 1 GeV and 25 GeV Gammas
- Assumed no the light detection efficiency change along the fibre
- Hit position evenly distributed in the detector volume



Simulation of 1 GeV (top) and 25 Gev (bottom) gamma



Result



Results

- Constant term bellow 1% everywhere
- Encouraging result to move to a full scale prototype

Conclusion

The GRAiNITA prototype has been characterized:

- Test beam with pions and muons
- Allows to accurately determine the light collection efficiencies
- Used as an input to G4 simulations
- Constant term bellow 1% is at reach
- The Light Yield previously reported has been confirmed (around 10kPE/GeV)

The pion data needed a dedicated treatment :

- Opportunistic model developed
- Educated with the muons fits

Next step :

- Design, build and characterize a full scale prototype